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Effect of Different Admixtures on Mechanical Properties of Concrete Paving Block: A Comparative Study

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ABSTRACT

Ever since their introduction nearly a century ago, concrete paving blocks have become increasingly common. They evolved into an alternative to burned clay brick and natural stone. Concrete paving blocks are used to lay down areas for vehicles and pedestrians as well. Durability is one of the most crucial elements in the production of high-quality concrete paving blocks. The aim of this study is to optimize the mechanical properties of concrete paving block units by experimenting with different admixtures. Compressive strength, water absorption, oven dry density, and drying shrinkage are among the attributes that were evaluated. The cost of production was also contrasted with and without the use of an admixture to achieve a comparable compressive strength. The results showed that admixtures could be used to produce high early strength units, and this was considered to be an economical factor in the production of concrete paving block units. At all ages, the use of admixtures increased these units' compressive strength by 30–40%. Although they did slightly increased density, additives also decreased the absorption and drying shrinkage of concrete paving block units.

Keywords: Concrete Paving Block; Admixture; Compressive Strength; Water Absorption; Oven Dry Density; Production Cost

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1. INTRODUCTION

One material that is frequently used in the construction sector is concrete. It is made by combining the necessary amounts of cement, water, fine and coarse aggregates, and occasionally admixtures [1]. Admixtures are a significant and increasingly common component of concrete mixes, even though they are not necessary like cement, aggregate, and water are [2,3]. In fact, a mix without admixtures is now the exception in many countries. The ability of admixtures to provide concrete with significant physical and financial benefits is the cause of the significant increase in their use [4]. Using concrete in situations where there were previously significant, or even insurmountable, challenges is one of these advantages. They also enable a greater variety of

ingredients to be used in the mixture [5]. The survival of the concrete industry is largely dependent on the adoption of clever technical solutions to address the growing concerns about environmental pollution caused by construction materials and activities and the scarcity of natural resources, such as water. Admixtures are required in order to produce concrete with the proper design strength at a low water cement ratio due to the availability of a variety of cements other than regular Portland cement [6].

Chemical admixtures are substances that are added to concrete in the form of powder or liquid to give it properties that aren't possible with standard concrete mixes [7]. Chemical admixtures are very little additions to concrete that are primarily used for air entrainment, water or cement content reduction, plasticization of fresh concrete mixtures, and setting time control [8]. Admixtures, while not always inexpensive, don't always mean spending more money because their application can save money on associated costs, such as labor costs for achieving compaction or increasing durability without the need for extra precautions [9].

Nevertheless, it was found that chemical admixtures lower construction costs, alter the characteristics of hardened concrete, guarantee concrete quality while mixing, transporting, placing, and curing, and resolve specific emergencies during concrete operations [10]. Admixtures composed of chemicals include water reducers, super plasticizers, set retarders, set accelerators, air entrainers, and specialty admixtures [11]. Chemicals known as additives are typically added to concrete to provide a variety of advantageous outcomes, including increased workability, enhanced strength and durability, acceleration, decreased void volume, improved plasticity, etc. [12]. In comparison to the weight of all components and the overall composition of concrete, the composition of additives varies from 0.02% to 0.5% [13]. Retarding admixtures, according to the European Federation of Concrete Admixture Associations (EFCA), work by influencing the hydration process, which lowers the rate at which water enters the cement particles and slows down the reaction rate (speed) between the cement and water [14]. On the other hand, certain admixtures have the ability to reduce water at a variety of dosages and, when used in large quantities, to speed up the concrete's compressive qualities. [15].

On the other hand, certain admixtures have the ability to reduce water at a variety of dosages and, when used in large quantities, to speed up the concrete's compressive properties [16]. Admixtures (retarders) for concrete setting time retardation can be inorganic (phosphates, borates, lead salts, etc.) or organic (lignosulphonates, hydroxycarboxylic acid, phosphonate, etc.). The quantity of water required to make the concrete more workable can be decreased by using a superplasticizer [17].

Long side chain polycarboxylic ether molecules improved fresh concrete performance, according to Sugamata et al.'s [18] investigation into the effect of the chemical structure of polycarboxylic ether-based superplasticizer on fresh concrete performance. When superplasticizers are used with hardened concrete, the concrete becomes denser and has a higher compressive strength due to improved compaction effectiveness [19]. The type of cement used, the makeup of the fine and coarse aggregates, the concentration of the aggregates, the water quality used, the admixture type, and the ambient conditions—mostly temperature—all have a significant impact on the engineering properties of concrete [20]. Particles with sizes ranging from 75 μm to 4.75 mm are typically found in fine aggregate, while those with sizes ranging from 4.75 to 50 mm are found in coarse aggregate. The ease and uniformity with which fresh concrete can be mixed, transported, and compacted—without experiencing undue bleeding or segregation—is typically used to assess the quality of the material. [21]. If the right amounts of fine and coarse aggregate are used, bleeding in newly mixed concrete can be minimized. Admixtures and a higher cement content can also aid.

Prior studies have demonstrated that the appropriate amount of admixtures can enhance the compressive strength of cement composite materials. According to Akpokodje and Uguru [22], sandcrete blocks made with cassava waste water (as an admixture) had a 39% higher compressive strength than blocks made with fresh water. According to Sanjeev et al. [23], concrete blocks' compressive and split tensile strengths increased when fly ash, ground granulated blast furnace slag (GGBS), and metakaolin were partially substituted for cement. According to Topçu and Ateşin [24], when fresh concrete made with a naphthalenesulfonate-based admixture was compared to fresh concrete made with a lignosulfonate-based admixture, the slump flow

results were better (better flowability). After 28 curing days, the compressive strengths of concretes made with modified polycarboxylic ether polymer (admixture) were found to be higher than those of concretes made with modified sulfonated polymer and synthetic polymer, according to a different study by Papayianni et al. [25]. The aim of this study was to optimize the mechanical properties of concrete paving block units by experimenting with different admixtures. Compressive strength, water absorption, oven dry density, and drying shrinkage are among the attributes that were evaluated. The cost of production also contrasted with and without the use of an admixture to achieve a comparable compressive strength.

2. MATERIALS AND METHODS

2.1. Cement

In this study, regular Portland cement (Local Brand) was utilized. It was brought into the lab and kept out of the rain. The chemical and physical characteristics of the cement are displayed in Tables 1 and 2 according to test results, the adopted cement complied with ASTM C150 Type I. [26].

Table 1. Chemical composition and main compounds of cement

Oxide composition	Abbreviation	Content percent	Limits of ASTM C150 Type I
Lime	CaO	62.00	–
Silica	SiO2	21.70	–
Alumina	Al2O3	6.57	–
Iron oxide	Fe2O3	2.11	–
Sulphate	SO3	2.20	≤ 3.0%
Magnesia	MgO	2.90	≤ 6.0%
Potash	K2O	0.21	–
Soda	Na2O	0.15	–
Loss on ignition	LOI	1.11	≤ 3.0%
Insoluble residue	IR	0.85	≤ 0.75%
Lime saturation factor	LSF	0.90	–

Table 2. Physical properties of cement

Physical properties	Test results	Limits of ASTM C150 Type I
Specific surface area, Blaine method (m^2/kg)	274	280 (min)
Soundness (auto clave method)	0.31	0.8% (max)
Setting time (vicat's apparatus) **Initial setting (minutes)** **Final setting (minutes)**	 112 217	 60 (min) 600 (max)
Compressive strength **3 days (N/mm2)** **7 days (N/mm2)**	 21 27	 12 (min) 19 (min)

2.2. Fine Aggregate

Throughout this work, nature sand with grading limits BS 882/1992 [27] and a maximum size of 4.75 mm was used. According to Table 3, the sieve analysis of the fine aggregate grading complied with BS 882/1992 [27]. Table 4 shows the specific gravity, absorption, and sulphate content, all of which meet the same specifications.

Table 3. Grading of fine aggregate

Sieve size (mm)	Cumulative passing	Limits of BS 882/1992
4.75	100.00	89-100
2.36	82.68	60-100
1.18	76.00	30-100
0.60	61.43	15-100
0.30	39.81	5-70
0.15	13.49	0-15
Fineness modulus = 2.27		

Table 4. Physical properties of fine aggregate

Physical properties	Test results	Limits of BS 882/1992
Specific gravity	2.52	–
Sulphate content	0.18%	0.5% (max)
Absorption	2.32%	–

2.3. Coarse Aggregate

The maximum size of the crushed aggregate that was used was 10 mm. The coarse aggregate grading in Table 5 is in accordance with BS 882/1992 [27]. Table 6 shows the specific gravity, sulphate content, and absorption of coarse aggregate.

Table 5. Grading of coarse aggregate

Sieve size (mm)	Cumulative passing	Limits of BS 882/1992
14.00	100	100
10.00	93	85-100
5.00	7	0-25
2.36	0	0-5

Table 6. Physical properties of coarse aggregate

Physical properties	Test results	Limits of BS 882/1992
Specific gravity	2.71	–
Sulphate content	0.07%	0.1% (max)
Absorption	0.86%	–

2.4. Admixture

This investigation employed two different forms of admixtures: i) polycarboxylate ether (PCE) and ii) lignosulfonate-based admixture. According to ASTM C494 Type F [28], polycarboxylate ether (PCE) is a light brown liquid with a long lateral chain that is free of chloride. This super plasticizer has a specific gravity of 1.05 at 25 degrees Celsius. It improves the strength, density, and workability of concrete, according to the earlier study. Using this high-range water-reducing admixture used in research, an efficient mixture can be created. PCE lowers water consumption by 15% to 20%. The lignosulfonate-based admixture has a specific gravity of 1.17 at 25 degrees Celsius and is a dark brown liquid that complies with ASTM C494 type C [28]. Water demand is reduced by 5–10% when this admixture is used at a dosage of 0.3–0.6% (weight of cement). Figure 1 shows two different admixture used in this study.

a) Polycarboxylate ether-based superplasticizer

b) Lignosulfonate-based admixture

Figure 1. Two different admixtures used in this study

2.5. Mix Design

Several slump tests were conducted in compliance with ASTM C143 [29] to determine the ideal admixture dosage that produces the greatest water reduction at the same workability and to adjust for the water content. According to these tests, the mix's maximum water reduction is 25%, which is equivalent to an admixture dosage of 1.5% by cement weight; water reduction stops at this dosage. Table 7 provides specifics about the mixes that were used in this investigation.

Table 7. Mix proportion of concrete paving block mixes

Mix designation	Mix ratio (Cement : FA : CA)	Water content	Cement content (kg/m3)	Type and dosage of admixture by weight of cement
Mix A	1:1.6:3	.48	395	-
Mix B	1:1.7:3.2	.36	395	1% Polycarboxylate ether based superplasticizer
Mix C	1:1.7:3.2	.32	395	1% Lignosulfonate-based admixture
Mix D	1:1.8:3.4	.36	395	1.5% Polycarboxylate ether based superplasticizer
Mix E	1:1.8:3.4	.32	395	1.5 % Lignosulfonate-based admixture

2.6. Mixing, Casting and Curing Procedure in Factory

In order to produce concrete paving block units, the experimental work was done in the Concord Ready-Mix and Concrete Products factory. Concrete's dry ingredients were added to the mixer to begin the material mixing process. To achieve a uniform mix, the materials were mixed for three minutes. After adding the necessary amount of water, the ingredients were thoroughly mixed for an additional three minutes. The admixture water content was deducted from the necessary amount of mixing water and the above procedure was applied to concrete. Concrete was mechanically moved from the mixer to the block-making machine using metal pans. The blocks were placed inside the mold, which vibrated. The head and shoes were lifted out of the mold during the filling process to make room for the concrete. The head and shoes pressed against the top of the blocks when the mold was filled and vibrated. As seen in figure 2, they were moved down to extrude the blocks from the mold at the conclusion of the vibration period. Following that, an excavator is used to move the concrete paving blocks to the storage area for curing, as depicted in figure 3. Concrete paving block units were cured in the factory by being left in the storage area and, depending on the weather, being sprinkled with

water. Figure 4 displays the final goods following the application of admixture.

Figure 2. After demolding from machine mold

Figure 3. Carrying to the storage place for curing

Figure 4. Finished products after the usage of admixture

3. RESULTS AND DISCUSSION

3.1. Compressive Strength

The ASTM C140 was followed in the execution of this test [30]. Table 8 and Figure 6 display the compressive strength of concrete paving block units for mixes with and without admixtures at various ages. The compressive strength of all units, both with and without admixtures, increases steadily with age. The compressive strength of the units increased to 45%, 49%, 35%, 46%, and 34% higher after 28 days of moist curing (sprinkled with water) than it was after three days for Mix A, Mix B, Mix C, Mix D, and Mix E, respectively. The units' compressive strength clearly increases as the amount of moist curing increases. When admixtures are used in the production of concrete paving block units, the factory curing time can be shortened because the finished units meet ASTM C90 [31], Grade-N1, requirements after just three days of moist curing. Mix A exhibits a higher compressive strength than mixes without admixtures, as demonstrated by the comparison with Mix B, Mix C, Mix D, and Mix E. This results from employing admixtures, which lowers the water content ratio. Even though pressed concrete is used to make concrete paving block units, the compressive strength of these units is increased by reducing the water content through the use of admixtures. Using these admixtures results in a roughly 30–40% increase in compressive strength for the produced concrete paving block units at all ages. Additionally, the use of admixtures gave the concrete paving block units that were produced an early strength, which could shorten the curing period. Mix B and Mix D, which contain superplasticizer based on polycarboxylate ether, have a lower compressive strength than Mix C and Mix E, which contain lignosulfonate-based admixture. It is also evident that a decrease in water content leads to an increase in compressive strength. Figure 5 displays the compressive strength testing of concrete paving block units.

Table 8. Compressive strength of hollow block concrete units

Mix Type	Compressive strength (MPa), at age (days)			
	3	7	14	28
Mix A	18.80	22.03	24.09	27.32
Mix B	24.09	28.79	31.73	35.84
Mix C	27.17	30.84	33.19	36.72
Mix D	25.35	30.58	32.99	37.10
Mix E	28.08	31.76	34.19	37.66

a) compressive strength test setup

b) typical rupture for a whole paving block

Figure 5. Compressive strength testing of concrete paving block units

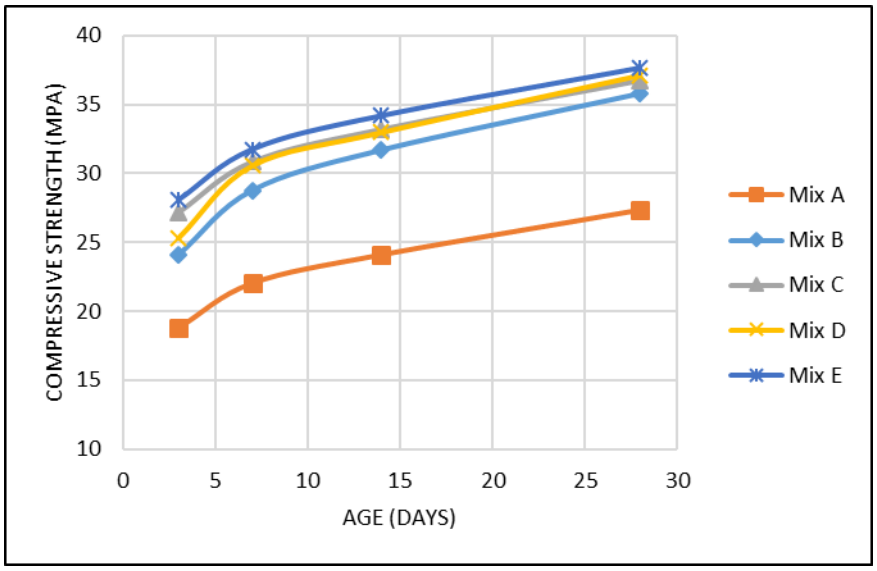

Figure 6. Development of compressive strength of different mixes of concrete paving block units with age

3.2. Absorption and Moisture Content

Table 9 displays the absorption and moisture content of concrete paving block units after 28 days of moist curing. These findings demonstrate that the use of admixtures reduces the absorption of concrete paving block units by lowering capillary porosity, which is brought about by a significant reduction in the water content ratio. Figure 7 shows the relationship between the concrete paving block units' compressive strength and absorption. Evidently, a reduction in absorption results in a rise in compressive strength. The moisture content results for each unit meet ASTM C90's type 1 [31] moisture-controlled unit requirements. Compared to Mix B and Mix D, which contain superplasticizer based on polycarboxylate ether, Mix C and Mix E, which contain lignosulfonate-based admixture, produce less absorption and moisture content. As the water content decreases, we can also see a decrease in absorption and moisture content.

Table 9. Absorption and moisture content

Type of mix	Absorption (%)	Absorption (kg/m3)	Moisture content (%)	ASTM C90
Mix A	5.70	126.92	36.10	Max. absorption 208 kg/m3
Mix B	4.13	100.70	28.50	
Mix C	4.04	93.10	29.45	
Mix D	4.07	96.71	29.07	
Mix E	4.01	90.44	29.74	

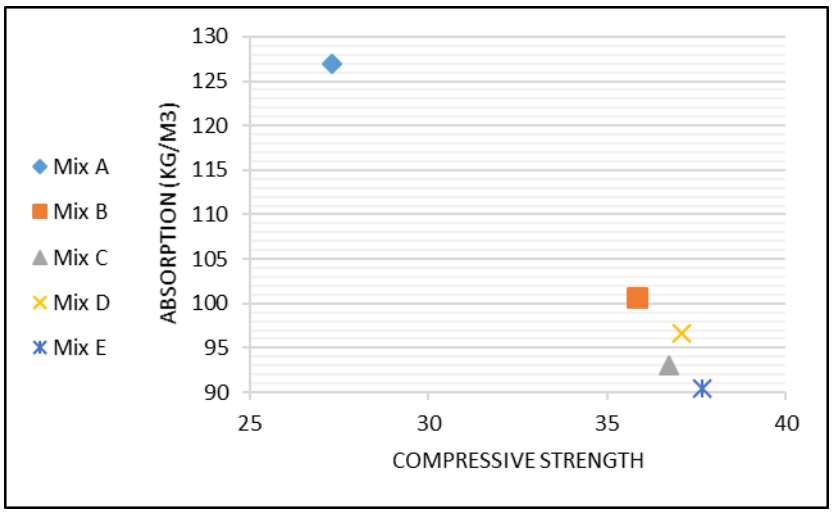

Figure 7. Relation between absorption and compressive strength for different mixes of concrete paving block units

3.3. Oven Dry Density

The ASTM C495 [32] was followed in determining the oven dry unit weight test. Table 10 lists the oven-dry density results at 28 days of age. Due to the admixture concrete's lower water content than the reference concrete, it is evident from the results that the units produced from Mix B, Mix C, Mix D, and Mix E (mixes containing admixtures) have a higher oven-dry density than units produced from Mix A. Figure 8 demonstrates how an increase in oven-dry density clearly raises a unit's compressive strength. Mix B and Mix D, which contain superplasticizer based on polycarboxylate ether, yield a lower dry density than Mix C and Mix E, which contain lignosulfonate-based admixture. We can also observe that dry density increases due to decrease in water content.

Table 10. Oven-dry density

Type of mix	Oven-dry density (kg/m3)	Drying shrinkage (%)	Percentage of shrinkage reduction (%)
Mix A	1543	0.028	–
Mix B	1565	0.016	43
Mix C	1579	0.012	57
Mix D	1569	0.015	47
Mix E	1585	0.011	60

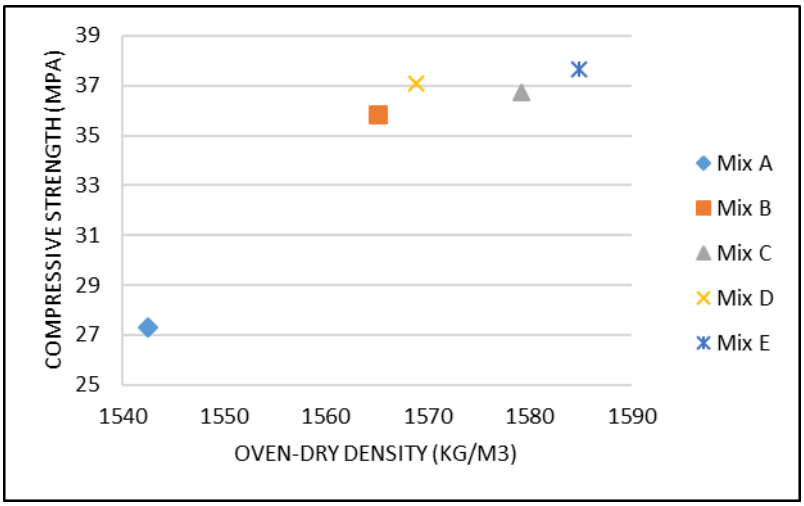

Figure 8. Relation between oven-dry density and compressive strength for different mixes of concrete paving block units

3.4. Drying Shrinkage

In accordance with ASTM C426 [30], this test was performed to ascertain the shrinkage of concrete paving block units. The drying shrinkage results for the concrete paving block units made with and without admixtures are displayed in Table 10. The findings demonstrate that admixtures reduce drying shrinkage. This results from employing these admixtures to lower the percentage of water in the concrete. Additionally, by using these admixtures, the aggregate volume percentage is increased. It is well known that concrete with a higher aggregate content shrinks less. Mix B and Mix D, which contain superplasticizer based on polycarboxylate ether, exhibit greater drying shrinkage than Mix C and Mix E, which contain lignosulfonate-based admixture. We can also observe that drying shrinkage decreases due to decrease in water content.

3.5. Production Cost

Production cost of concrete paving block units decreased due to the usage of admixtures. By adding admixture high strength concrete can be produced. From this study it can be observed that, by adding admixture high strength concrete block was produced in spite of increasing aggregate ratio, which decreased the usage of cement and reduced the overall production cost of concrete paving block units. Table 11 shows the production cost of concrete paving block units for different mixes.

Table 11. Production cost of concrete paving block units for different mixes

Mix Type	Per Unit Price
Mix A	BDT 25.00
Mix B	BDT 23.50
Mix C	BDT 23.20
Mix D	BDT 22.50
Mix E	BDT 22.25

4. CONCLUSION

The following deductions are made in light of the investigation's findings:

1. By increasing the concrete paving block units' early age compressive strength, admixtures used in their manufacturing process enable a shorter curing time.
2. Using admixtures results in a 30–40% increase in compressive strengths for the produced concrete paving block units at all ages.
3. The use of admixtures lessens the absorption of concrete paving block units.
4. The oven-dry density of concrete paving block units is slightly increased by the use of admixtures.
5. The drying shrinkage of the produced concrete paving block units is decreased by approximately 40–60% when admixtures are used.
6. High strength concrete blocks were produced even with an increased aggregate ratio by adding admixture, which reduced the amount of cement needed and the overall cost of producing concrete paving block units.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this

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